THERMAL DEFOLIATION IN 2004

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Abstract

Organic cotton production requires alternative methods to harvest aid chemicals for crop termination and harvest preparation. Conventional cotton production occasionally requires greater control over the timing of crop termination and harvest preparation. Trials were conducted to determine the impact thermal defoliation has on plant physiology, yield and fiber value under various conditions. A self-propelled two-row prototype thermal defoliator was tested in eight fields at six locations in three states, with differing intervals between treatment and harvest. Desiccation, defoliation and open boll percentages were quantified at some locations, and seed cotton trash content and classing office data were recorded at others. Thermal defoliation resulted in crop termination in all four climate zones, successfully preparing all seven varieties for harvest. Thermal defoliation resulted in greater leaf kill and less leaf drop compared to standard harvest aid chemical treatments. Thermally defoliating cotton six days after treating the crop with ethephon resulted in a greater percentage of open bolls compared to standard harvest aid chemical treatments, thermal treatment alone, and no treatment. At the two locations where ginning and classing have been completed, fiber values were not statistically different ($p < 0.05$) between thermal and control treatments. Thermal defoliation appears to give growers greater control over harvest timing without adversely affecting fiber value.

Introduction

Organic production precludes the use of harvest aid chemicals. Alternative methods are required for preparing organic cotton for harvest. Conventional harvest aid chemicals require time and favorable weather conditions to be effective (Logan and Gwathmey, 2002). Additionally, these chemicals do not protect the crop from insect sugar deposits. Thermal defoliation not only facilitates organic production, it may prove helpful when a conventional cotton crop is threatened by bad weather or late season sucking insects.

Thermal defoliation was initially explored as an alternative crop termination tool for organic cotton production. While verifying thermal defoliation's efficacy, we observed very rapid leaf kill and realized harvesting within 48 hours of thermal treatment might be practicable. Harvest timing treatments were evaluated in 2003 and 2004 to quantify the effects of early harvest on yield and fiber quality. Because the near-immediate and total destruction of green leaves might also drive away late season sucking insects responsible for stickiness, thermal defoliation treatments were included in a University of California study combining harvest aid chemicals with insecticides.

Thermal defoliation studies were conducted with a tractor-towed one-row experimental thermal defoliator for two seasons to prove the concept and to quantify crop response to various combinations of speed and temperature. Fiber and yarn quality for both thermal and conventional harvest preparation were measured in 2002. Slightly higher fiber values from better leaf and color grades were found with thermal defoliation (Funk et al., 2004a). Based on these initial studies, a self-propelled two-row prototype thermal defoliator was constructed to quantify field efficiencies and fuel consumption (Funk et al., 2004b).

Defoliation and harvest timing affect lint yield and quality (Gwathmey et al., 2004). Although it is often desirable to defoliate and begin harvest operations early in the harvesting season, the beneficial effects of delayed cotton termination (additional yield and improved fiber quality, as well as once-over harvesting) must be weighed against the risks of inclement weather becoming more probable (Larson et al., 2002). Objectives for the 2004 crop year experiments were to quantify the effects on fiber value and yield of both thermal and control treatments with the number of days between treatment application and harvest from seven cultivars grown at eight locations. Boll opening, leaf drop and insect mortality responses were recorded at selected locations. Aerial multi-spectral nearinfrared images were taken of two thermal defoliation experiment fields near Weslaco, TX to confirm crop response to thermal and control treatments by remote sensing.

Materials and Methods

Thermal Defoliator

The two-row prototype thermal defoliator constructed for this research was designed and built based on field trial results from tests conducted with a one-row experimental thermal defoliator in 2001 and 2002 (Funk et al., 2004a). The platform used to support the defoliation apparatus was initially a corn detasseling unit. It came equipped with an open tilt cab, two-wheel steering, four-wheel hydrostatic drive, auxiliary hydraulic power and a six cylinder gasoline engine. The platform had 2 m (6 ft) of ground clearance, providing space for the defoliation apparatus.

The defoliation apparatus was suspended beneath the platform and could be raised with hydraulic cylinders to facilitate field maneuvering and loading for transporting. The defoliation apparatus consisted of a framework of rectangular steel tubing supporting crop dividers, treatment tunnels, fans, a burner, and distribution and return air duct work. Two propane fuel tanks, two electric vaporizers, a gas train with meter, regulator, pilot, safety and control valves, and a 50 kW generator were added to the platform to complete the prototype unit. The engine was converted to burn propane fuel from the same pair of 303 l (80 gal) tanks that supplied the burner (Figure 1). Approximate run time between refueling stops was eight hours.

Figure 1. Thermal defoliation apparatus used in the 2004 trials. USDA-ARS photo by P. Funk

The prototype thermal defoliator auxiliary hydraulic pump powered a 22.4 kW (30 Hp) motor which powered two centrifugal fans. The fans supplied 9,970 l s^{-1} (21,130 cfm) of air to a 732 kW (2,500,000 BTU/h) propane burner where the air was heated to 193 C (380 F). Hot air from the burner was forced through the cotton plants as the plants passed through one of two 0.61 x 0.61 x 4.57m (2 ft x 2 ft x 15 ft) treatment tunnels. One side of each tunnel was lined with 2.51 cm (1 in) diameter hot air nozzles. The other side of each tunnel was lined with perforated metal to serve as a return air flow path. Roughly 66% of the treatment air was recirculated to conserve energy. The selected ground speed was inversely proportional to crop density to maintain a constant treatment temperature.

<u>Weslaco, TX</u>

At the Weslaco location (USDA-ARS-Kika de la Garza Subtropical Agricultural Research Center), the physiological response of cotton plants to thermal and control treatments was observed in two fields located 3 km (2 mi) apart. DP-5415-RR (Delta and Pine Land Co, Stoneville, MS) was planted in both fields on March 2nd, 2004. Thermal defoliation and two control treatments, chemical and no defoliation, were randomly assigned within each of six replicate complete blocks at both locations (Figures 2 and 3). The thermal treatments were applied on July 21st. Thermal treatments consisted of forcing air at an average temperature of 163 C (325 F) through the cotton canopy while traveling at 0.45 m s^{-1} (1 mph) for a dwell time of 10 seconds. Each thermal treatment consumed an average of 162 l ha^{-1} (17.3 gal/acre) of propane for a fuel cost of \$56.92 ha^{-1} (\$23/acre). Propane cost \$0.35 l^{-1} (\$1.33/gal) delivered. The chemical control treatment, s,s,s-tributylphosphorotrithioate (DEF, Bayer Co., Kansas City, MO) was applied at a rate of 1.6 kg ha^{-1} (1.37 pint/acre) the next morning.

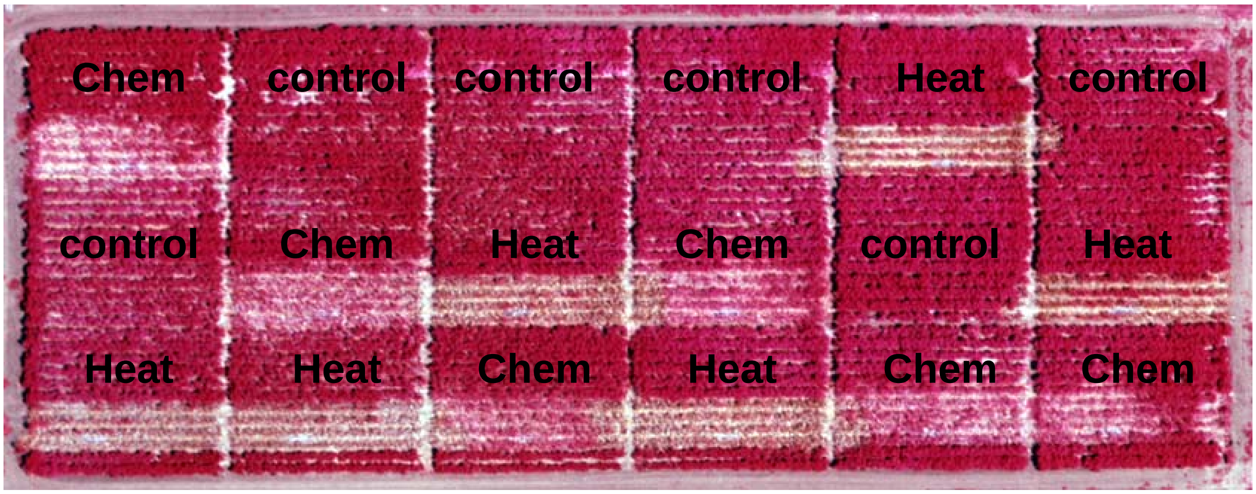

Figure 2. USDA-ARS-KDLG SARC (Weslaco, TX) Panhandle Site 27 July 04. Color-infrared photograph acquired at an altitude of 1500 ft above ground level from a fixed-wing aircraft 6 days after treatments. The thermally treated areas (4 rows beneath label 'Heat') have a red to brown color on the image. USDA-ARS photo by R. Fletcher.

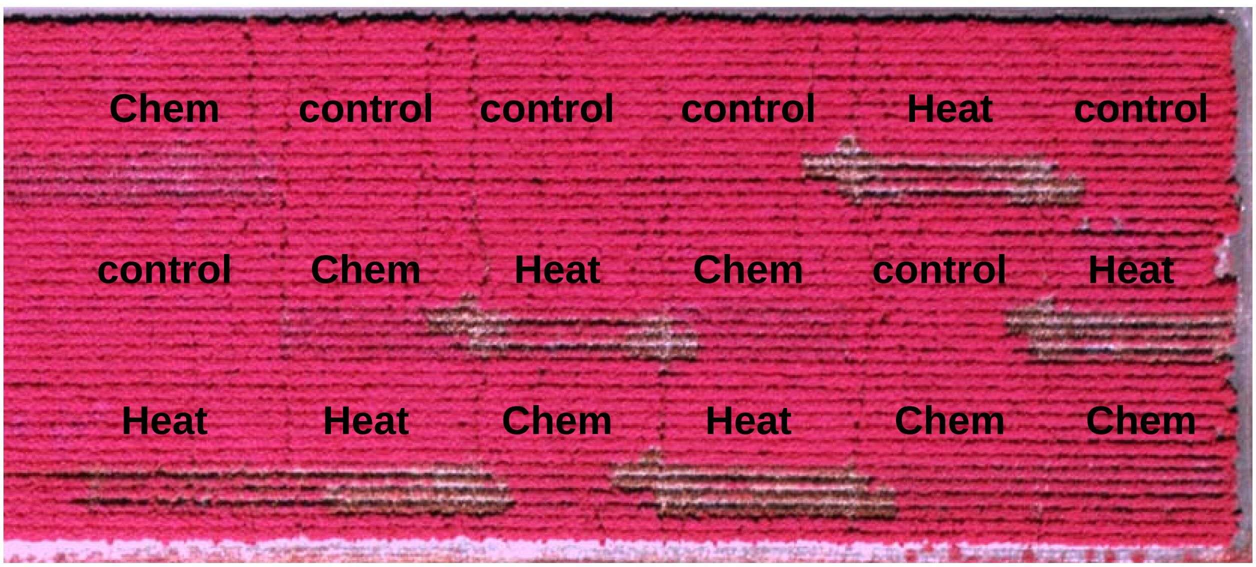

Figure 3. USDA-ARS-KDLG SARC (Weslaco, TX) Ansul Site 27 July 04. Color-infrared photograph acquired at an altitude of 1500 ft above ground level from a fixed-wing aircraft 6 days after treatments. The thermally treated areas (4 rows beneath label 'Heat') have a red to brown color on the image. USDA-ARS photo by R. Fletcher.

Ten randomly selected plants in each plot were marked for counting green, dead and abscised leaves. Leaves were counted 0, 1, 3, 5, 7, 9, 11 and 13 days after treatment. Leaves were considered dead when abscised or when no green tissue was visible. Color-infrared aerial photographs were taken from a fixed wing aircraft flying at an altitude of 457 m (1500 ft) above ground level on July 27th, six days after treatment.

San Joaquin Valley, CA

Defoliation treatments and harvest timing were evaluated in terms of fiber value at two locations in the San Joaquin Valley (SJV). An SJV approved variety, C-104 "Sierra" (Roundup Ready), was grown at the University of California's (UC) West Side Research and Extension Center Field #47 near Five Points, CA. The same cultivar was grown at the Kern County/UC/USDA-ARS Shafter Research and Extension Center "South 40" Field #44 near Shafter, CA, approximately 120 km (75 miles) southeast of the West Side location.

Four plots each were thermally defoliated 48 and 24 hours before the research stations' field days, on September 14th and 15th at the West Side location and on September 19th and 20th at the Shafter location, so visiting growers could see the results after one and two days. West side treatments averaged 0.23 m s^{-1} (0.51 mph) for a dwell time of 20 seconds, and 236.7 l ha^{-1} (25.3 gal/acre) for a fuel cost of \$86.86 ha^{-1} (\$35.20/acre). Shafter treatments averaged 0.27 m s^{-1} (0.61 mph) for a dwell time of 18 seconds, and 200.6 l ha^{-1} (21.45 gal/acre) for a fuel cost of \$73.62 ha^{-1} (\$29.79/acre). The local September propane price (delivered) was \$0.367 l^{-1} (\$1.389/gal).

The control treatment consisted of a standard tank mix of harvest aid chemicals applied in a manner typical of the area. For the West Side control treatment an initial defoliant and boll opener application on September 17th of 0.438 l ha^{-1} (6 oz/acre) thidiazuron + diuron (GinStar, Aventis CropScience, Research Triangle Park, NC) and 2.338 l ha^{-1} (1 qt/acre) ethephon (Prep, Aventis CropScience, Research Triangle Park, NC) was followed seven days later by a second defoliant application of 0.438 l ha^{-1} (6 oz/ac) thidiazuron + diuron and a desiccant application of 2.338 l ha^{-1} (1 qt/acre) paraquat (Gramoxone, Syngenta Crop Protection, Greensboro, NC). The Shafter control treatment was a September 20th defoliant application of 0.468 l ha^{-1} (6.4 oz/ac) thidiazuron + diuron.

Four replicates at each location were harvested 48 hours after thermal treatment. Additionally, at the West Side location, four replicates of thermally defoliated cotton were harvested 21 days after treatment and four replicates of the control (chemical defoliation) were harvested 18 days after chemical treatment. At the Shafter location, three replicates were harvested 17 days after thermal treatment and three replicates were harvested 16 days after chemical treatment. Seed cotton from each replicate was transported to the USDA-ARS-Southwestern Cotton Ginning Research Laboratory near Las Cruces, New Mexico for ginning.

Each lot was ginned separately after passing through two inclined cleaners and one combination burr-stick machine. Ginning was followed with two stages of lint cleaning. Initial and final weights were recorded to calculate turnout and yield. Replicated seed cotton and lint samples were taken from each stage of the ginning process to determine moisture and trash content (Shepherd, 1972). Replicate lint samples were collected after ginning and after each stage of lint cleaning and shipped to the USDA-AMS-Cotton Program Phoenix Classing Office for high volume instrument (HVI) analysis (USDA, 2001). The HVI grade and USDA loan price were used to calculate fiber value.

Lubbock, TX

Harvest timing and plant response to boll opener applied prior to thermal defoliation were quantified in stripper harvested cotton (FiberMax 989BR, Bayer CropScience, Research Triangle Park, NC) at Liberty Field #3, a remote site connected with the USDA-ARS Cotton Production and Processing Unit near Lubbock, TX. A boll opener (1.53 l ha^{-1} (21 oz/acre) ethephon) was applied October 13th. Thermal defoliation treatments were applied on October 19th. Treatment speed was 0.34 m s^{-1} (0.76 mph) for a dwell time of 13.7 seconds. Fuel consumption was 176 l ha^{-1} (18.8 gal/acre), resulting in a fuel cost of \$46.00 ha^{-1} (\$18.61/acre) at the then current local delivered cost of \$0.26 l^{-1} (\$0.99/gal). The chemical control treatment applied October 20th was 1.53 l ha^{-1} (21 oz/acre) ethephon plus 0.584 l ha^{-1} (8 oz/acre) thidiazuron + diuron. Flagging was used to mark 3 m (10 ft) long sections in two rows of each plot. The total number of green and open bolls was recorded for each row section before, 20 and 42 days after treatment to estimate the percentage of open bolls.

Stripper harvesting was delayed by unseasonable rains. Thermal treatments were harvested October 25th, November 8th, and November 30th (6, 20 and 42 days after treatment). The thermal plus boll opener treatment was harvested October 25th (6 days after treatment), and the Chemical control and after frost treatments were harvested November

30th (41 days after treatment). All treatments were field cleaned, and ginned within a day of harvest. Each lot was ginned separately after passing through two inclined cleaners and two combination burr-stick machines. Ginning was followed with two stages of lint cleaning. Initial and final weights were recorded to calculate turnout and yield. Three to five replicate lint samples were taken after ginning and after each stage of lint cleaning and shipped to the USDA-AMS-Cotton Program Phoenix Classing Office for HVI analysis.

La Union, NM

A commercial-scale demonstration of thermal defoliation in organic production was conducted on 28 Ha (68 acres) at the Price Dairy near La Union, NM. The field was divided between Acala 1517-77 (6 Ha (14 ac)) and Pima S-6 (22 Ha (54 ac)). The field was planted April 15th after alfalfa, and last irrigated August 20th. Mechanical cultivation and pink bollworm pheromone strips were the only interventions, in keeping with organic practices. Thermal treatment was applied to 4.8 ha (12 ac) of Acala and 2 ha (5 ac) of Pima at the end of September (27-30 Sept, 01 Oct.) (Figure 4). Harvesting was delayed until December 10th by unseasonable rains. The thermally defoliated and untreated Pima were formed into separate modules; thermally defoliated Acala was placed in a separate module, and the untreated control Acala was harvested and stored in a cotton trailer. Due to the late harvest date, cotton from this study has not been ginned as of the 2005 Beltwide Cotton Conferences.

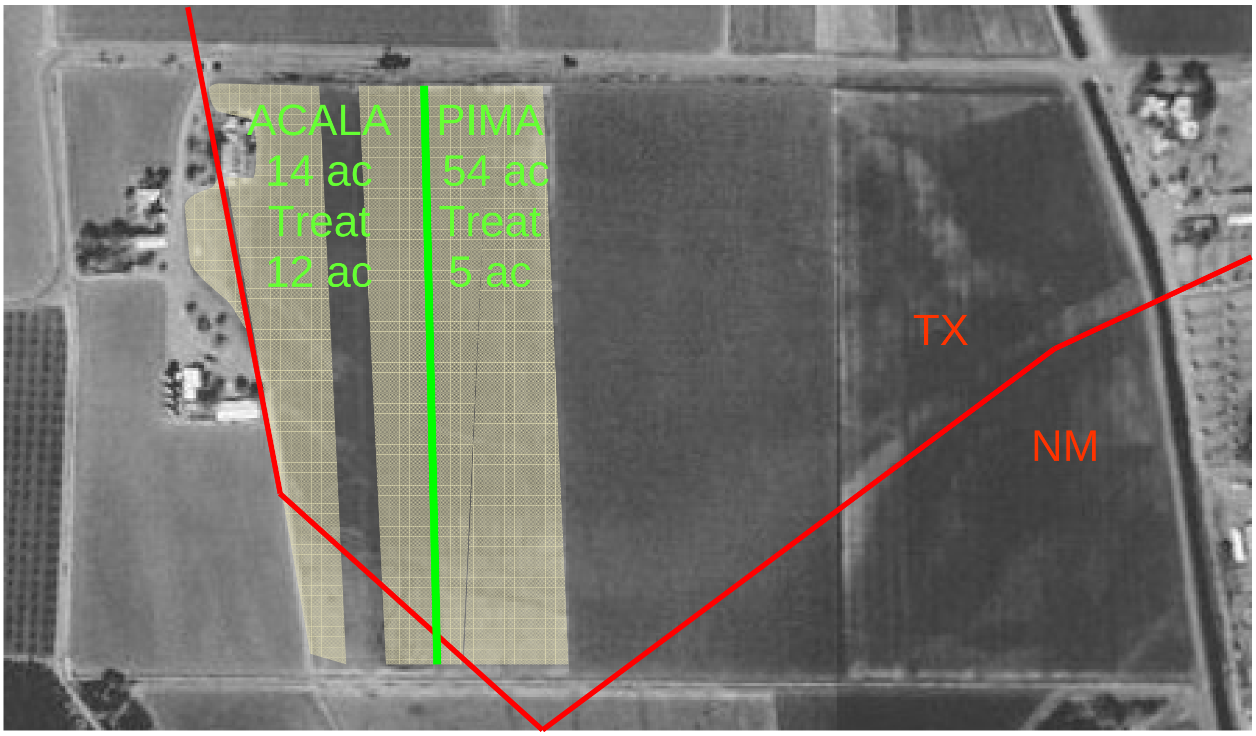

Figure 4. Aerial photograph showing the parts of the organic cotton field near La Union, NM that were thermally defoliated from Sept. 27 through Oct. 1, 2004.

Las Cruces, NM

Two cultivars (Acala 1517-99 and Delta Pine 565) were randomly assigned to plots planted at the end of April at New Mexico State University's Leyendecker Plant Science Research Center (PSRC). Thermal treatments were applied on October 21st, four weeks after the last irrigation, at 0.32 m s^{-1} (0.72 mph), for a dwell time of 14.6 seconds. Thermal treatment consumed 206 l ha^{-1} (22.04 gal/acre), for a fuel cost of \$98.50 ha^{-1} (\$39.89/acre) at the then current local delivered cost of \$0.48 l^{-1} (\$1.81/gal). Unseasonable rains delayed the chemical control treatment eight days, to October 29th. The control treatment applied to three replicates of each cultivar was 2.34 l ha^{-1} (2 pt/acre) each of tribufos (Folex, Amvac Chemical Corp., Newport Beach, CA) and ethephon + cyclanilide (Finish, Bayer CropScience, Research Triangle Park, NC).

Flagging was used to mark 3 m (10 ft) long sections in two rows of each plot. There were 36 plots, three replicates of six treatments in two cultivars. The total number of green and open bolls was recorded for each row section before and 19 days after treatment to estimate the percentage of open bolls. A two-row spindle picker harvested thermal treatments 11, 18 and 28 days after treatment. Chemical treatments were harvested 12 and 27 days after treatment. The untreated control (green) treatment was harvested a day before the last thermal treatment was. Due to the late harvest date, cotton from this study has not been ginned as of the 2005 Beltwide Cotton Conferences.

Results and Conclusions

Weslaco, TX

Physiological response to thermal treatments was similar to prior years. Leaf kill was nearly complete within 24 hours, though most of the leaves remained on the plant. Chemical control treatments were eventually better at leaf removal, but not leaf kill. Multi-spectral near infra-red aerial photographs taken six days after treatment show the difference, especially in the second field 3 km (2 mi) south of the USDA-ARS-Kika De La Garza Subtropical Agricultural Research Center ("Ansul"), Figures 2 and 3.

San Joaquin Valley

Seed cotton trash levels were significantly higher for thermal defoliation treatments (2.88%) as compared to the chemical control treatments (2.16%), and higher still (3.51%) in thermally defoliated cotton harvested two days after treatment (Table 1). However, differences between treatments were no longer statistically significant ($p < 0.05$) after the seed cotton had passed through seed cotton cleaning equipment at the gin. Leaf trash levels in ginned lint and classing office high volume instrument (HVI) leaf grades favored thermal defoliated cotton (Table 1), as shown previously (Funk et al, 2004a). Although more leaves remained on the plants with thermal defoliation, the dry, crumbly nature of thermally defoliated leaves made it easier for seed cotton and lint cleaning equipment to remove them. This also resulted in a slightly higher loan value, based on better leaf and color grades, though loan value was not statistically different.

Table 1. San Joaquin Valley, CA seed cotton and fiber properties, average of Shafter and West Side

TREATMENT	Leaf Trash in Seed Cotton After Harvest (%)	Leaf Trash in Seed Cotton After Cleaning (%)	Classing Office HVI Leaf Trash (%)	Classing Office Leaf Grade	Classing Office HVI Color Grade (+B)	USDA Loan Price based on Grade ($/lb)
Chemical Control	2.16	0.53	.221	2.29	8.64	$0.5678
Two Week Thermal	2.88	0.58	.186	2.14	8.50	$0.5671
Two Day Thermal	3.51	0.66	.219	2.50	8.93	$0.5680
Significance ($p < 0.05$)	-n.a.-	NS	NS	0.0473	0.0095	NS

Lubbock, TX

Before thermal defoliation and chemical control treatments were applied, Liberty Field #3 averaged 62% open boll. Boll opening counts twenty days later indicated that only one treatment, boll opener applied before thermal defoliation, differed substantially from the average. Applying 1.53 l ha^{-1} (21 oz/acre) of ethephon six days before thermal defoliation resulted in 99% open bolls after 20 days, where all other treatments averaged 84% open bolls (Table 2). This likely explains the 15% greater yields realized in plots treated with boll opener compared to the thermal treatment plots harvested the same date. All treatments benefited from waiting a longer period, as open boll percentages were 100% by the 30^{th} of November, after several frost events, when the last thermal and two control treatments were harvested. Yields were comparable 20 to 42 days after treatment, averaging three percent more than the thermal-on-boll opener treatment and 19 percent more than the first thermal treatment yields recorded six days after treatment. While drawing conclusions is difficult from a single crop year, there appears to be enough benefit from using boll opening chemicals in combination with thermal defoliation to justify the added expense, should early harvest be called for due to weather or insect concerns.

Table 2. Lubbock, TX field results; yield and percent open bolls before and 20 days after treatment

TREATMENT	Harvest Date (Days After Treatment)	Yield (Lb/ac)	Open Bolls 19 Oct (Before Treatment) (%)	Open Bolls 8 Nov (20 Days After Treatment) (%)
Thermal on Boll Opener	25 Oct (6)	884	63	99
Thermal only	25 Oct (6)	766	62	84
Thermal only	8 Nov (20)	919	57	80
Thermal only	30 Nov (42)	925	61	84
Chemical Control	30 Nov (41)	903	65	85*
Untreated Control	30 Nov	915	65	86

* Chemical treatment was applied the next morning, so this count is actually 19 Days After Treatment.

La Union, NM

Total fuel consumption, including engine needs, warm-up periods, leaks, etc., was 318 l ha^{-1} (34 gal/acre). Due to unseasonable rainfall, harvest was delayed several weeks after frost, finally starting December 10^{th} (74 days after treatment!) Despite the two and a half month interval and several hard frost events, visible differences between thermal and control treatments persisted. Data is unavailable at this time as the cotton has not yet been ginned.

Las Cruces, NM

Leyendecker PSRC thermal treatments were applied when the Delta Pine 565 cultivar was at 58% open boll, and the Acala 1517-99 was 69% open. Nineteen days later they both were 97% open boll, with no significant differences between treatments or cultivars ($p < 0.05$). Clear differences in leaf kill were visible between treatments (Figure 5); however, fiber data is unavailable at this time as the cotton has not yet been ginned.

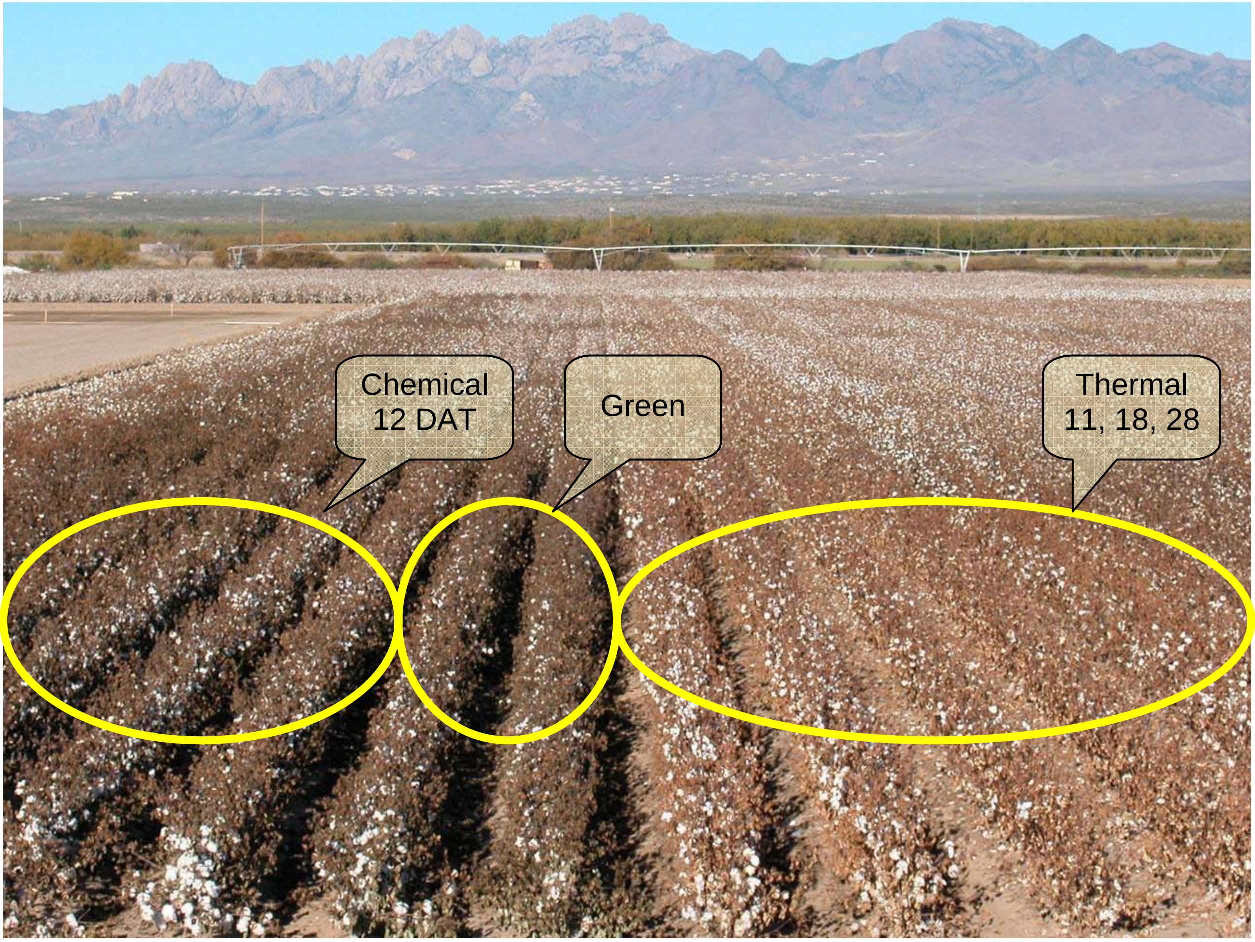

Figure 5. Photograph showing response to thermal defoliation nine days after treatment. Numbers indicate interval between treatment and harvest in days, green is the untreated control. USDA-ARS photo by P. Funk.

Future research should examine the potential increase in yield and fiber value possible with later termination while harvesting on the same date.

Disclaimer

Mention of trade names or commercial products in this article is solely for the purpose of providing information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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